Chapter 4

Sources and Toxicology of Lead Exposure

Contents:

Introduction

There are multiple sources of lead in the environment which pose a unique threat to the developing minds and capacities of young children. The affects of lead depend on the age of the individual at the time of exposure, and the level and longevity of exposure. The primary source of exposure for adults is in the workplace. For children, the primary exposure is from dust formed from deteriorated lead-based paint or varnish. The lead dust makes its way into the body through normal hand-to-mouth activities of very young children.

This chapter provides information on the history of lead as a toxin, how the body metabolizes lead, the toxicity of lead, and the most common sources and routes of lead exposure.

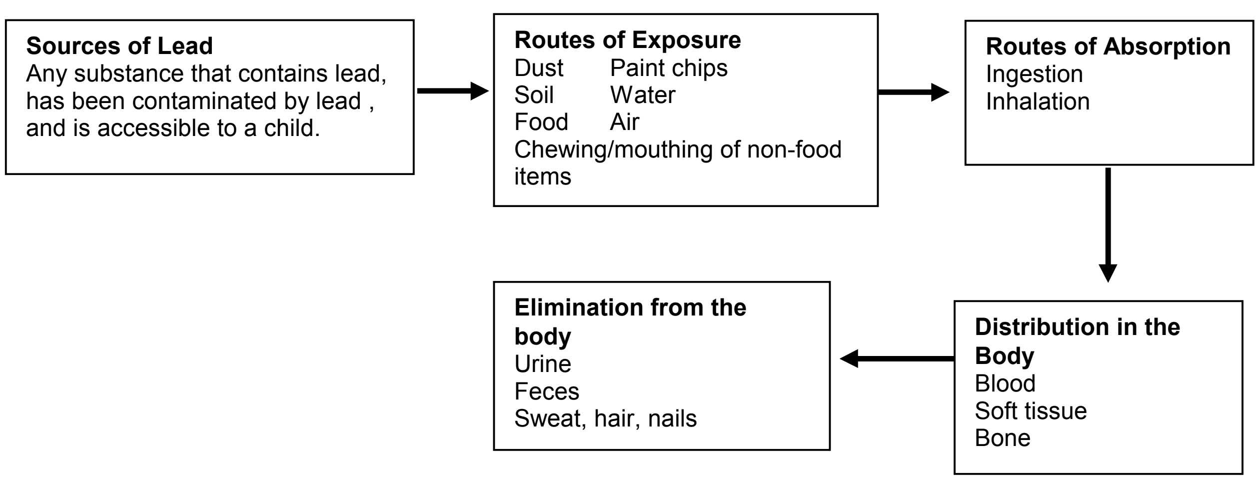
Lead Poisoning in Human History

Lead is ubiquitous in modern industrialized societies, and evidence of the negative affects of lead on humans has been noted for centuries. For more information on the history of the uses of lead, it's toxicity, and the role of the lead paint industry in the research and promotion of lead, see "Footsteps Through History: Lead Poisoning" at the end of this chapter. This can be adapted for power point or slide presentation. WCLPPP had used it as an actual path during the LOFL 2000 conference

Lead in the Human Body

Just as the sources of lead exposure in children vary from adults, so does the way a child's body metabolizes and is affected by lead. Figure 4.1 shows the path lead takes in a child's body from exposure (usually through hand-to-mouth activity) to elimination.

Figure 4.1
Lead Sources and Routes of Exposure



Absorption of Lead in Children's Bodies

The primary site of absorption of lead in children is the gastrointestinal tract. Ingestion through hand-to-mouth activity is the primary manner in which children introduce lead into their bodies. Children absorb up to 50% of the lead they ingest, about five times as much as adults. Gastrointestinal absorption is enhanced by a fasting state, iron or calcium deficiency, and/or high fat diets. No feedback mechanism causes a decrease in the absorption of ingested lead once levels become elevated.

Lead is absorbed rapidly through the lungs when inhaled. Up to 70% of inhaled lead is absorbed, depending on particle size. The primary source of inhaled lead had been emissions from automobiles using leaded gasoline. Since the decrease in leaded gasoline levels, the total amount of lead inhaled by children is small compared to the amount ingested.

Absorption of lead through the skin is minimal. Lead poisoning in children through dermal exposure is rare, primarily because children's contact with these elements is limited.

Distribution of Lead in a Child's Body

Once absorbed into the child's system, lead is distributed in three body systems: blood, soft tissue, and bone. The concentration and mobility of lead within each compartment varies (see Figure 4.5)

The blood lead level (BLL) is the most direct measurement of body lead, although it represents only about 5-10% of the total body lead burden. Once in the blood, up to 99% of lead is bound to erythrocytes and cannot diffuse across cell membranes. Approximately 1-10% is bound to microligands in the plasma. It is this pool that is capable of crossing cell membranes and therefore can become biologically active. Because lead is found primarily in the red blood cell rather than plasma, there are implications when collecting capillary blood lead samples. If the finger is squeezed too hard, a blood sample may be obtained that is higher in plasma, resulting in a BLL that is falsely low. Lead readily binds to fetal hemoglobin (for more information, see Chapter 13).

Figure 4.5 Distribution of Lead in the Body

	Blood	Soft Tissue	Bone
Half-life	35 days	40 days	Spongy (pelvis, ribs, skull): 3-5 years Cortical (midtibia, midfemur): 30 years
% total body burden	5-10%	10-20%	70-85%

Source: Lead Poisoning in Childhood, S. Pueschel, J. Linakis, A. Anderson

About 10-20% of lead retained in the body is stored in soft tissues such as kidney, liver, bone marrow, and brain. It is in these sites where lead has the most toxic effects to children. The toxic effects vary inversely with the age of the poisoned child: the younger the child, the more vulnerable the sites are to lead exposure. The extent of damage to soft tissues is related directly to the amount and duration of exposure: the longer the exposure, the more severe the effects. In other words, the younger the child and the longer the exposure, the greater the severity of the effects is likely to be.

The remainder of lead retained by the body is stored in the bones. The half-life of lead in bone can be up to 30 years, and throughout that time it seeks to create a steady-state with blood lead. As the BLL drops due to chelation and/or decreased exposure, lead migrates from the bone to blood, and may be the cause of a prolonged elevated blood lead level. Bone-to-blood migration may also occur during pregnancy and lactation in women with high bone lead levels, which may have developed in early childhood (see Chapter 13).

Elimination of Lead from Children's Bodies

An estimated 60% of absorbed lead is eliminated from the body. The primary route of elimination is through the kidney, followed by feces, hair and nail growth, and sweat loss

In animal studies comparing lead metabolism in infant and adult rats, lead was cleared from the blood much more slowly, and localized in the brain to a greater degree in infant rats.

Primary Effects of Lead Toxicity in Young Children

The Centers for Disease Control & Prevention identifies lead as the number one environmental health threat to young children. Lead toxicity can have an adverse affect on virtually every system in the body. The result of lead toxicity can be seen in the peripheral nervous, hematopoietic, renal, and gastrointestinal systems. It effects the regulation of vitamin D, and the growth, hearing, and cognitive development of a young child. Most importantly, it can cause irreversible damage to the central nervous system. At very high levels, lead exposure can cause seizures, coma, and death.

Continued research on lead toxicity in children has caused a rapid decrease in the blood lead levels of concern for children. As recently as the early 1960's, the level of concern for children was 60μg/dL. In 1985 that level was lowered to 25μg/dL, and to the current level of 10μg/dL in 1991. That decrease was prompted by an acceptance of widespread research that showed damage from lead at BLLs as low as 10μg/dL to the central nervous system of young children, causing developmental delays, lower IQ, hyperactivity, learning disabilities, behavioral problems, and school failure. Physical effects noted at this level include impaired hearing, slowed growth, and nephropathy. In the fall of 2002, two national panels began to examine the research on the negative affects of even small amounts of lead on children's intelligence. They will make recommendations on whether the CDC should lower the "acceptable level of lead in a child's blood (from 10μg/dL set in 1991).

Animal research on the effects of lead on brain structure and function demonstrate multiple cellular and synaptic disruptions caused by lead. These disruptions in cellular anatomy and neurotransmitter systems can be noted by the breakdown in their function of modulating emotional response, memory, learning and visual-spatial relationships. Studies have persistently shown a correlation between low-level lead exposure during early brain development and deficits in neurobehavioral-cognitive performance that manifest later in childhood. The effects demonstrated in several longitudinal studies have been consistent across cultures, racial/ethnic groups, and social/economic class.

In the first research that specifically looked at a large number of children with BLLs known to be <10μg/dL, deficits in cognition and academic abilities associated with lead exposure have been noted. Adjusting for factors known to have an impact on these outcomes, children with BLLs $\geq 3\mu g/dL$ demonstrated impairment in cognitive, memory and visual-spatial skills. The adverse effects of lead on reading and other language-based abilities was significant, as these are potent predictors of academic achievement and anti-social behavior. This study further supports the research that has indicated no threshold for lead toxicity.

Research indicates that lead exposure during the first 3 years of life has the most damaging and long-lasting effects. At this stage, the child's developing brain is most vulnerable to toxic exposures. One study indicated that a stronger predictor of school-age intellectual function was elevated blood lead at any level at an early age, than even higher BLLs in older children.

A publication by the Wisconsin Council on Children and Families on brain development and the impact of environmental factors can be found at the end of this chapter. Entitled "Great Beginnings: The First Years Last Forever", the paper summarizes early brain growth, critical periods of development, and how environmental factors during these stages can affect long-term growth and development of the child. For more information on brain development, see the Council's website at www.wccf.org.

Prenatal lead exposure has been associated with increased risk of pre-term delivery, reduced birth weight, and reduced performance on neurological testing. For children whose subsequent lead exposure is low and who receive developmentally appropriate stimulation, there is evidence that the damaging neurological effects associated with prenatal exposure may be reversible (see Chapter 12).

Sources & Routes of Lead Exposure

On the following pages are brief descriptions of the commonly identified sources of lead exposure and the vehicles or routes by which they enter a child's body. It is important to remember that lead-based paint and varnish is the primary source of lead poisoning among children in Wisconsin and nationwide.

1. Source: Lead-based paint and varnish

Exposure to lead-based paint (LBP) is the major source of lead poisoning for children. When lead paint is intact, it is unlikely to cause exposure. The risk of exposure increases as the paint breaks down into smaller particles. The smaller the particles, the more easily they are dispersed, become accessible to children, and are absorbed by the body. If lead paint is allowed to deteriorate due to normal wear (moisture damage, temperature changes, friction, or impact), or when paint is deliberately disturbed by renovation activity, house dust and soil become contaminated. The resulting lead dust and chips can enter a child's body through normal hand-to-mouth activity.

Routes of Exposure:

• Lead dust created by deteriorating lead-based paint (LBP) or renovation activities can stick to fingers, toys, soil, food, and other accessible surfaces. Young children are then likely to ingest the lead dust through normal hand-to-mouth activity. This is the most common route of exposure for children.

• LBP is a hazard if it is peeling, chipping, chalking, or cracking. LBP that appears to be undisturbed can be a problem if it is on surfaces that rub together (friction surfaces) or surfaces that children chew, such as windows and window sills, doors and door frames, stairs, railings and banisters, porches, fences, and/or furniture.

• Surfaces that have been covered with new paint or another covering can expose layers of LBP if they are consistently rubbed, or when they become cracked or chipped.

• Lead in varnish is typically found on floors, door and window casing, trim and even old baby cribs.

• LBP that is intact, undisturbed, and inaccessible to young children may not pose a lead hazard and should be left alone.

2. Source: Industrial Source/Occupational

Industries that produce and/or use lead in manufacturing can create lead hazards. A list of industries identified with EBLLs among workers is listed in Figure 4.3. Short-term construction trade activity can also be a source of high dose exposure to LBP.

Figure 4.3

Industries Linked to Elevated Blood Lead Levels	
secondary smelting/refining of nonferrous metals	storage batteries (lead batteries)
valve & pipe fittings (except plumber's brass goods)	brass foundry
plumbing fixture fittings & trim (brass goods)	glass products made of purchased glass
motor vehicle parts/accessories	firing range workers
pottery makers	chemical & chemical preparations
bridge, tunnel, & elevated highway construction	automotive repair shops
industrial machinery & equipment	inorganic pigments
primary batteries, dry & wet	

Source: Bader and Marion, 1990; Maizlish et al., 1990.

Routes of Exposure:

• Lead-emitting industries such as smelters and battery manufacturing plants can cause lead contamination of air, soil, and food grown in contaminated soil.

• Adults working in industries or other occupations involving exposure to lead may be directly exposed and/or may carry lead-contaminated dust on hair, clothing, and shoes home to their families.

3. Source: Hobbies

Hobbies that involve lead or lead containing materials (Figure 4.4) can cause exposure if steps are not taken to contain the lead and keep it away from children.

Figure 4.4

Hobbies Involving Lead Products
casting ammunition, fishing weights, or toy soldiers soldering stained glass making pottery and using lead glazes refinishing furniture using art supplies containing lead such as paints, glazes, or colored pencils Source: Adapted from CDC Manual, 1991

Routes of Exposure:

- Eating, drinking, or smoking in the work area.
- Hands or clothes worn while working can become contaminated and expose children through contact. People involved in these hobbies are advised to avoid contact with children until they have showered and changed clothes.
- Lead contaminated dust from these hobbies can be spread to other areas of the home where children play or spend time.

4. Source: Toys, Children's Products and Other Household Products

In 1978, regulation of the commercial manufacturing of toys and children's products in the United States became more stringent for lead content. However, lead is periodically identified in products made in the United States or imported. Concern about the content of lead should be raised for toys imported from Southeast Asia, Central and South America, Eastern European countries, and Mexico.

Examples of widely used products that have been found to contain lead are candles with leaded wicks, vinyl mini and vertical blinds, and car keys. Any products built before 1978, such as toys, playground equipment and furniture, should be regarded as containing lead until tested.

If you would like current information on product recalls contact CPSC directly at 800-638-2772 or visit their web site, http://www.cpsc.gov. You can also contact the WI Dept. of Agriculture at (608) 224-4944 or visit their web site, http://datcp.state.wi.us/.

Routes of Exposure:
Mouthing, chewing, or ingesting dust or paint from products that contain lead.

5. Source: Traditional Home Remedies and Cosmetics

In some cultures, families may use remedies or cosmetics that contain lead (see Figure 5.5). Use of powder remedies containing lead for cosmetics or medical conditions is often steeped in traditions that may be unfamiliar to health care professionals in the U.S. It may take several interactions with the family to gain their trust and willingness to inform you of how, why, and which of these medicines or cosmetics they may use. If possible, obtain a sample of the suspected medicine or cosmetic to be analyzed for lead at the Wisconsin State Laboratory of Hygiene.

Figure 5.5

Traditional Home Remedies/Cosmetics Containing Lead		
Culture/use of product	*Name(s) of product*	*Description of product*
Latino: abdominal pain called "empacho"	Alarcon, azarcon, coral, greta, liga, rueda	Yellow or Orange powders
Asian Indian: intestinal disorders	Ghasard Bali goli Kandu	Brown powder Flat black bean Red powder
Hmong: fever or rash	Pay-loo-ah	Red powder
Arabian: cosmetic, treatment for infections of the skin or umbilical stump	Kohl or akohl Surma Ceruse	Powder

Route of Exposure:
Direct ingestion if taken as a medication or mouthing hand-to-mouth if topical application such as a cosmetic.

6. Source: Plumbing fixtures and pipes that contain lead

The most common source of contamination of drinking water is lead in plumbing solder. Contamination from lead pipes, lead connectors, and lead service lines is less frequent. Brass or bronze plumbing and well parts that have lead added to increase the malleability may be disguised by a chrome coating. The small wire mesh screen at the spigot end of the faucet can trap lead solder particles and contaminate the water. Where lead is present in plumbing, contamination is increased by corrosive water (acidic or low mineral content, "soft" water), the length of time the water sits in the pipes, and hot water.

Routes of Exposure:
Water that passes through lead containing plumbing fixtures or pipes can become contaminated and become a hazard when used in drinking, cooking, or food and formula preparation.

7. Source: Dishware

The lead content of commercial dishware, pottery and crystal manufactured in the U.S. is regulated. However, if these items are imported from countries without such regulation they may contain dangerous amounts of lead in glaze or glass. On occasion, the Consumer Product Safety Commission (CPSC) has recalled products that contain unsafe amounts of lead, such as imported ceramics and dishware.

If you would like more information on product recalls contact CPSC directly at 800-638-2772 or visit their web site, http://www.cpsc.gov. The State of Wisconsin, Department of Agriculture, Trade and Consumer Protection, also conducts product recalls and notices on unsafe products. You can contact the WI Dept. of Agriculture at (608) 224-4944 or visit their web site, http://badger.state.wi.us/agencies/datcp

Routes of Exposure:
- Ingestion of contaminated foods stored in dishes with leaded glaze or paint or leaded crystal.

- Acidic foods and beverages, such as tomato sauce, coffee, juice or wine can exacerbate the leaching of lead when prepared or stored in leaded containers.

8. Source: Lead-Based Solder in Cans

The lead solder used to seal cans may contaminate the food it contains. In 1995 the U.S. banned the use of lead solder in food or soft drink cans, but it is still used in many other countries and may still be found in cans imported to the U.S.

Routes of Exposure:
Ingestion by children of food or beverages stored in cans with lead-soldering.

9. Source: Leaded Gasoline

Leaded gasoline contributes directly to air lead levels. Fallout from the air causes contamination of soil, dust, and crops. Lead in soil does not biodegrade. Annual emissions of lead from gasoline have fallen dramatically since the mid-1970s, when the lead content of gasoline was regulated. The decline of lead in gasoline has been accompanied by a decline in the mean BLLs of the United States (U.S.) population. However, leaded gasoline is still used in other countries, and children who are adopted or immigrate from these countries should be tested for lead poisoning.

Routes of Exposure:

- Exhaust from leaded gasoline stays in the top several inches of soil.
- Children playing on or in the soil may be exposed
- Food grown in contaminated soil may contain lead

Societal Costs of Lead Poisoning In Children

Societal costs of lead poisoning include increased incidence of poor school performance, behavior disorders, and anti-social behavior among children who are lead poisoned. Difficulties achieving in school can lead to classroom disruption, increased costs for special education, and decreased potential of the effected child. In 3 major prospective studies, a persistent inverse relationship was found between elevated BLL up to 10 years of age, IQ and/or school performance.

Behavior changes noted among children with lead poisoning range from hyperactivity, distractibility, low tolerance for frustration, increased fearfulness, social withdrawal, increased aggression, unwed pregnancy, and higher involvement in crime. A history of elevated BLLs has been found among juveniles and adults incarcerated in the nation's prison system.

Lead was the number one cause of poisoning deaths in children during the 1940s. Mortality from lead poisoning is rare today. The long-term outcome for a child exposed to lead appears to rely as heavily on the child's age and length of exposure as on the severity of exposure. Research findings of the effects of lead at BLLs previously thought to be safe forces the focus of activities to prevention and screening efforts to decrease morbidity. (For more information on developmental assessment and impact on children with lead poisoning, see Chapter 12).

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Revised 10/9/2003

Great Beginnings: The *First Years Last Forever*

As we approach the birth of a new millennium, with all that
Fresh beginnings imply, we are filled with hope and anticipation.
And nowhere is the future more celebrated than in the
Genuinely precious gift of each new child.

A society is measured not only by its ability to overcome obstacles,
but by its ability to nurture opportunities.

And it all begins with babies.

Johnson & Johnson

It all begins with babies…and their brains. The first three years are a critical period in the development of every child. The experiences of that child will influence the way in which the brain grows – the way in which the brain is wired. For example, if a baby hears a lot of rich, descriptive words, s/he is likely to be much more able to think conceptually than children whose caregivers do not talk with them very often.

Why are the first three years so important…because the brain is NOT fully developed at birth. However, by age three, 85% of the core structures are in place. So an infant or toddler who sees few pictures, few colors, hears less conversation, feels little affection and loving touch, actually has a brain that is 20-30% *smaller* than a child who is loved, cuddled, and nourished. A warm, nurturing environment with consistent loving adults and caregivers will give a child the foundation for a promising future. A hostile or sterile living environment coupled with inattentive, emotionally unpredictable, or changing caregivers will leave a child with diminished potential.

The impact of the environment is dramatic and specific, not merely influencing the general direction of development, but specifically affecting how the intricate circuitry of the human brain is 'wired'.

How the Brain Develops

The brain grows in sequential fashion, from bottom (brainstem) to top (cortex), or from the least complex part (brainstem) to the more complex area (cortex).

Brainstem – at the base of the skull

- Controls the most basic life activities, including heart rate, blood pressure, & body temperature.

Cerebellum or midbrain – near the base of the skull behind the brainstem

- Controls movement, appetite, & sleep.

Limbic system – inner, central portion of the brain

- Controls emotional reactivity, attachment, affect regulation, long-term memory.

Cortex – top layer of the brain, about the depth of two dimes placed on top of each other

- Controls logical thinking, reasoning, abstract thought, emotional mediation.

Take Care! Neurons at Work

While many cell types make up brain mass, the neuron is the brain cell which mediates the activities that we associate with brain function – thinking, feeling, seeing, etc. We are born with roughly 100 billion neurons which connect with one another through synapses to form networks that connect to form systems. The systems work together to allow specific activities, such as vision, to occur. For instance, in the region of the cortex that controls vision (occipital lobe), there are a number of "visual maps" or systems of neurons that respond to different components of sight, i.e., color, form, motion. Yet, the individual sees a synthesized "picture." What happens to the child, both prenatally and during the first years of life will determine how these brain cells move from the more primitive, or lower, areas of the brain up to the limbic and cortical regions. The environment also inhibits or reinforces the connections (synapses) that occur between brain cells.

Neurons on the Move

Because the different systems in the child's brain develop at different times, neuroscientists have determined that specific parts of the brain require environmental stimulation during specific times in a child's life. If a child is deprived of visual stimulation during the first few months of life, that child will have permanent visual impairment. The critical windows are associated with the migration and differentiation (taking on a specific, rather than a general, function) of neurons. As Dr. Felton Earls states:

> In complex organisms, neurons must travel from the proliferative area in which they are generated to distant zones where they differentiate and establish permanent connections with other neurons…These events occur at specific times in the developmental cascade and a missed "opportunity" cannot be compensated for at a later time as the conditions have changed and the developmental potential has become constrained or limited by subsequent events.

Knowing that the different systems develop at different times and that environmental stimulation is necessary for normal development, tells us two important things:

1. A child must receive the appropriate "signals" from the environment - they must hear language to learn language; they must be able to see in order to develop vision; they must be cuddled, loved, and touched to understand human connection.
2. If environmental cues are missing during critical times of development, the parts of the brain regulating these activities do not develop appropriately.

What about the Environmental Cues? What Happens?

Appropriate environmental stimuli, at the appropriate times, strengthen the neuronal synapses and when the stimuli are repeated they reinforce the synapses in a use-dependent fashion.

❑ Vision – in the occipital lobe, there is a spurt in neuronal synapse formation between months two and four that peaks at the eighth month when a single neuron may connect to as many as 15,000 other neurons depending upon the visual experiences of the child. If a child is born with a congenital cataract, it must be removed early in life; age two is too late – the neuronal connections between the eye and the brain will have failed to form.

❑ Language – by six months of age, the auditory map (temporal lobe) in a child from a Spanish-speaking family looks different than the auditory map of a child in an English-speaking family. Research has shown that children who are language-deprived are less able to think conceptually at age four than children who have a rich language experience (hearing a lot of descriptive words spoken with an encouraging, loving voice).

❑ Touch – children, deprived of touch, do not exhibit normal body or brain development; attachment behavior is affected because the part of the brain (parietal lobe) involved in attachment does not develop normally; the "wiring" is less dense because of sensory deprivation.

> Such a person is literally lacking some brain organization that would allow him to actually make strong connections to other human beings. Remember the orphans in Romania? They're a classic example of children who, by virtue of not being touched and held and having their eyes gazed into, didn't get the somatosensory bath.
>
> Dr. Bruce Perry

When Things Go Wrong

Trauma and abuse can cause significant damage to the developing brains of young children. Increased levels of cortisol wash over the brain, causing parts to be 20-30% smaller than in normal brains. In addition, certain brain systems appear to be sensitized by repeated traumatic experiences (use-dependent phenomenon), so that these children may exhibit hyperactivity, anxiety, and/or impulsive behavior. Dr. Megan Gunnar, University of Minnesota, states, “Kids from high stress environments [have] problems in attention regulation and self-control.”

Public Policy Implications

The brain holds the key to our highest potential as human beings. If programs and policies can increase the number of children who will become intelligent, empathetic, productive adults and decrease the number of children who will require special education, mental health, child protective, and juvenile justice services, than government ought to ensure those programs and policies.

- The first provider for each child is the parent(s). Parenting resources such as home visiting programs should be accessible statewide.
- Programs should be accessible statewide
- Demand and support high standards and adequate funding for child care, foster care, and child protective services.
- Integrate key principles of child development and caregiving into public education. We require more formal education for driving a car than rearing a child.

Source: Wisconsin Council on Families and Children, 2000.